DYNAMIC ANALYSIS OF OCEAN INTERNAL WAVES USING SPACE SHUTTLE DATA

Vic Klemas
Center for Remote Sensing
College of Marine Studies, University of Delaware
Newark, DE 19716
Tel.: (302)831-8256 fax: (302)831-6838
email: klemas@mingming.cms.udel.edu

Quanan Zheng
College of Marine Studies, University of Delaware
Newark, DE 19716
Tel.: (302)831-4698 fax: (302)831-6838
email: zheng@mingming.cms.udel.edu
Award #: N00014-97-1-0648 and N00014-95-1-0065

LONG-TERM GOALS

Long-term goals of the project are to develop suitable techniques for extracting quantitative data and information on ocean internal waves from space shuttle photographs and SIR-C images, to determine statistical features of the wave packet structures, and to analyze the generation, propagation, and collision of the waves, as well as the effects of boundary conditions.

OBJECTIVES

Continuing our studies of statistical and dynamical analysis of internal waves on the continental shelf and in the deep ocean, the project is focused on observation and analysis of internal wave and other air-sea boundary phenomena in the Arabian Sea. The objectives that pertain to 1997 are: to develop a geometric correction method specifically suited for space shuttle photography, to investigate statistical characteristics of wavelengths of internal solitons and numbers of solitons in a packet for various water depths, and to study the effects of bottom topography and coastline on internal wave propagation.

APPROACH

Data and Orthorectification Since 1981 the United States has performed Space Shuttle missions. After 15 years of operations, a Space Shuttle Earth Observations Project (SSEOP) database has been set up. Among the photographs, about 75% represent the globally distributed coastal zone. The database has been made easily accessible to the research community (Ackleson, 1992). Our center serves as a Space Shuttle Earth Imagery Analysis Center for analyzing, storing, re-processing, and distributing the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**
4. TITLE AND SUBTITLE **Dynamic Analysis of Ocean Internal Waves Using Space Shuttle Data**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Delaware,College of Marine Studies,Center for Remote Sensing,Newark,DE,19716**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

photographs to regional users. Therefore, we receive the original films of space shuttle photography two to three weeks after the mission. These near real-time data constitute a major data for our research. The image orthorectification is critical for quantitative studies of ocean dynamics using space shuttle photography in order to remove geometric distortion of target images. For space shuttle photography, however, there are no specific methods or software available and, therefore, had to be developed by ourselves.

Recognition and Interpretation The directly measurable quantities on space shuttle photographs are not always traditional ones from the point of view of conventional geosciences. It is necessary, therefore, to interpret or translate these quantities into traditional forms for theoretical or numerical calculation. For this purpose, the correspondence or transfer function between the two must be set up for individual features. This means that the photographic mechanism of the target should be first clarified and sometimes needs to be formularized. Theoretical Analysis The equations and formulae will be used for understanding the nature, physics, mechanism, and laws of variation in the process studied; deriving the unknown parameters using the measurable parameters as inputs; analyzing the relation between the studied processes and the surrounding environment; and predicting the future state of the processes studied.

Key Individuals Dr. V. Klemas, PI, serves as a leader of the project. He is in charge of planning and organizing, data interpretation and analysis, and writing the proposal and reports. Dr. Q. Zheng serves as a major scientist on the project. He is in charge of writing the proposal and reports, method development, data interpretation, and theoretical analysis.

WORK COMPLETED

Data Collection We have archived 17 rolls of 70 mm space shuttle imagery taken during missions STS-80 in December 1996, STS-81 in February 1997, STS-82 in March 1997, STS-83 in April 1997, and STS-84 in June 1997. All of the data were provided by NASA Johnson Space Center.

Special Presentations We gave two special presentations on space shuttle observations of air-sea boundary processes in the Arabian Sea. The first one was at the ASLO 97 Aquatic Sciences Meeting in Feb. 1997, in Santa Fe, NM, and the second at the U.S. JGOFS Arabian Sea Data Workshop in July 1997, in Durham, NH. The total audience was around 60 scientists.

Interpretation and Analysis of Space Shuttle Photographs This is continuous work supported by ONR starting in 1995. This year, we completed studies of digital orthorectification methods, dynamics of ocean internal waves in the Arabian Sea, and the dynamics of coastal lee waves. Four papers, partially supported by the project, were published or submitted:

Zheng, Q., V. Klemas, X.-H. Yan, Z. Wang, and K. Kagleder, 1997. Digital orthorectification of space shuttle coastal ocean photographs, Int. J. Remote Sensing, 18, 197-211.

Zheng, Q., X.-H. Yan, C.-R. Ho, V. Klemas, Z. Wang, and N.-J. Kuo, 1997. Coastal lee waves on ERS-1 SAR images, J. Geophys. Res., in press.

Zheng, Q., X.-H. Yan, W. T. Liu, and V. Klemas, 1997. Coastal lee waves observed from space, Proceedings of 2nd Conf. Coastal Atmos/Oceanic Prediction, in press.

Zheng, Q., X.-H. Yan, W. T. Liu, V. Klemas, D. Greger, and Z. Wang, 1997. Dnoidal solitons in the atmosphere observed from space, Geophys. Res. Lett., submitted.

RESULTS

Methods for Digital Orthorectification Previous investigations have demonstrated that space shuttle photography has widespread usefulness for oceanographic studies. Space shuttle photographs can be used not only for discovering phenomena of interest, but also for quantitative measurements. Sun-glitter photographs were used for observations of upper ocean processes on Georges Bank and the Gulf of Maine (La Violette, et al., 1990). Time series photographs of the Delaware Bay have been used for deriving tide-related parameters of the bay (Zheng, et al., 1993a). On this visible band imagery, oceanic internal waves in sunglitter areas can be sharply imaged. The information extracted from the photographs was used in statistical and dynamic analysis of internal waves both on the continental shelf (Zheng, et al., 1993b) and in the deep ocean (Zheng, etal., 1995a, 1995b).

According to photographic principles, it is impossible to avoid geometric distortions of a target in space shuttle imagery. This is caused by a variety of factors even though the hand-held cameras are perfect. These distortions cause the scale of the imagery to be compressed gradually from the nadir to the edges of a photograph. Measurements of distances, areas, angles, and directions made from raw or unrectified photographs contain errors caused by such scale compression. In the case of vertical photography, these errors may be negligible only at a relatively small area near the nadir and for large enough targets. Otherwise, the photographs must be first rectified before they can serve as an image map, if measurements with satisfactory accuracy are required. The digital orthorectification methods were developed specifically for space shuttle photography. The improvement in the accuracy were quantitatively assessed by comparing the departures of the coastline on unrectified and rectified photographs with a standard map. The maximum departure of the coastline in unrectified photograph STS-36-82-75 from the standard map is 3.3 km, and that on STS-36-82-76 is 1.6 km. Both of them decrease to less than 0.5 km in rectified photographs. The maximum departure of cloud imagery in the two unrectified photographs is 6 km, and it decreases to zero in rectified ones.

Investigating the Dynamics of Ocean Internal Waves Using space shuttle photographs and SIR-C SAR images, statistical features of ocean internal waves in the Arabian Sea were obtained. In the deep ocean the wavelength distribution is Gaussian, but in the coastal ocean it is Rayleigh. The average number of solitons per packet is around 3 or 4, and the largest 18. The mean wavelength of solitons varies from 0.4 km in the coastal ocean near Bombay, India, to 0.9 km near the Somali coast, and 1.8 km in the equatorial Indian Ocean. The dynamic parameters of internal solitons near the Somali coast were derived with a finite-water depth model. The results showed a maximum amplitude of 20 m, characteristic phase speed of 0.9 m/s, and period of 30 min. An interesting case, in which the propagation directions of soliton packets were offshore and parallel to the shoreline, was observed. Occurrence of these unusual phenomena was attributed to the reflection and deflection of tidal waves due to topographic variation. Another interesting case, in which crest lines of solitons were sharply deformed, was also observed in the Gulf of Aden near the Somali coast. Analysis indicated that this deformation might be a response to sharp variations in thermocline depth, which resulted from sharp changes in the bottom topography.

Observing Soliton Collisions Solitons are a type of wave motion which may exist in various media such as fundamental particles, plasmas, solids, and fluids including the atmosphere and ocean. The internal waves in the ocean are a type of classical soliton. The collision or interaction of solitons is a classical problem in soliton physics (Ze et al., 1979). Based on the collision theory of solitons in plasmas, the characteristic half width or the wavelength of the solitons are derived to be constant during their collision (Miles, 1977; Newell and Nagasawa, 1980). From the space shuttle data, collisions of solitons in the ocean were investigated, and the results compared to classical collision theory. The oblique collision of two multisoliton packets shown on space shuttle photographs was examined. The resultsshow that deepwater internal waves obey the general properties of soliton collision. The leading solitons and a few followers exhibit some properties of inelastic collision characterized by a phase-shift, and the rest of the solitons exhibit properties of elastic collision under resonance conditions.

IMPACT/APPLICATIONS

The results of this project were published in internationally circulated journals and presented at international symposia. These were significant contributions to improve our understanding of the behavior of ocean internal waves in the studied ocean areas, and constitute a contribution to upper ocean dynamics. Our research also demonstrates that space shuttle photography may play an important role in observations of various oceanic phenomena, in particular for remote ocean areas, which are far away from the fields of view of ground station antennas used by other earth observing satellites.

TRANSITIONS

Due to our continuous efforts to apply space shuttle photography to oceanography and our productive results, we won a project awarded by NASA to set up a regional analysis and distribution center for space shuttle photographs. The center has provided the data to about 30 internal and external users. The center also serves as an educational facility. Two Ph. D. students and four visiting students from Germany finished their degree/certificate research related to analysis and application of space shuttle data. The P.I. of this project has been invited to be a member of NASA's Space Shuttle Science Advisory Panel. We made several invited presentations at related conferences and workshops. Some scientists asked for copies of space shuttle photographs for their own research, and some suggested we edit an atlas of space shuttle photographs and put it in the public domain. We sent them data on CD-ROM and are preparing a new proposal to ONR for editing a global atlas on ocean internal waves.

RELATED PROJECTS

NASA Grant NAG9-789, Astronaut Training Guide for Space Shuttle Studies of Upper Ocean Dynamics.

REFERENCES

Ackleson, S. G., 1992. A summary of hand-held ocean and coastal photography taken during space shuttle missions: 1981-1991 (Abstract), EOS, Transactions, American Geophysical Union, 72, 69.

La Voilette, P. E., D. R. Johnson, and D. A. Brooks, 1990. Sun-glitter photographs of Georges Bank and the Gulf of Maine from the space shuttle, Oceanography, 3, 43-49.

Miles, J.W., 1977. Obliquely interacting solitary waves, J. Fluid Mech. 79, 157-169.

Newell, A.C. and T. Nagasawa, 1980. Oblique collision of plane ion-acoustic solitons, Phys. Rev. Lett. 45, 1626-1629.

Ze, F., N. Hershkowitz, C. Chan, and K.E. Lonngren, 1979. Inelastic collision of spherical ion acoustic solitons, Phys. Rev. Lett. 42, 1747-1750.

Zheng, Q., X.-H. Yan, and V. Klemas, 1993a. Derivation of Delaware Bay tidal parameters from space shuttle photography, Rem. Sen. Environ., 45, 51-59.

______, 1993b. Statistical and dynamical analysis of internal waves on the continental shelf of the Middle Atlantic Bight from space shuttle photographs, J. Geophys. Res., 98, 8495-8504.

Zheng, Q., V. Klemas, and X.-H. Yan, 1995a. Dynamic interpretation of space shuttle photographs: Deepwater internal waves in the western equatorial Indian Ocean, J. Geophys. Res., 100, 2579-2589.

Zheng, Q., V. Klemas, X.-H. Yan, and Z. Wang, 1995b. Application of space shuttle photography to studies of upper ocean dynamics, Proceedings of 1995 Shuttle Small Payload Symposium, NASA Conference Publication 3310, pp. 275-284.

Zheng, Q., V. Klemas, X.-H. Yan, Z. Wang, and K. Kagleder, 1997. Digital orthorectification of space shuttle coastal ocean photographs, Int. J. Remote Sensing, 18, 197-211.